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ABSTRACT

This monograph describes the development of a scope and sequence model for science education specifically intended for use with gifted students in grades K-8. Introductory material notes the rationale and purpose of the model as well as its functions such as providing a scaffolding linking educational concepts with the technology of school curriculum. The three stages of the 21-month project are outlined. Instructional emphases of the curriculum are: (1) scientific habits of mind; (2) critical/productive thinking skills; and (3) metacognitive skills. Ways to further differentiate the curriculum are suggested, such as varying the level of the outcome and varying the sophistication of the content. Desired outcomes are grouped into generic concept outcomes and scientific process outcomes with associated assessment indicators. Specific outcomes are listed by approximate grade level for concepts; content applications (in biology, earth science, physical science); interdisciplinary applications (social systems, number systems, cities as systems, language, political systems, economic systems); the scientific process; problem-based learning; technology (computer, camera, and calculator skills); scientific habits of mind (stressing curiosity, creativity, objectivity, openness to new ideas, and skepticism); critical/productive thinking skills; and metacognitive strategies (planning, monitoring, assessing). Guidelines for using the model for unit development are also offered. (DB)

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Developing Science Curriculum for High Ability Learners K-8 Series

Titles in this series include:

- A Conceptual Overview of Science Education for High Ability Learners
- Curriculum Assessment Guide
- Consumer's Guide to Science Curriculum
- Guide to Science Concepts
- Scope and Sequence of K-8 Science Curriculum for High Ability Learners
- Creating a New Science Curriculum
- Exemplary Teaching Units at K-2, 3-5, and 6-8 Grade Levels
- Notes from a Scientist: Suggested Resources and Activities for Gifted Children

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The United States Department of Education

College of William and Mary
School of Education
Center for Gifted Education
Williamsburg, Virginia

1992

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DEVELOPING A SCOPE AND SEQUENCE IN SCIENCE FOR HIGH ABILITY LEARNERS K-8

by

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The College of William and Mary
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1992

Rationale and Purpose

Scope and sequence models are sometimes viewed as too restrictive in their orientation, not allowing teachers the freedom necessary to create meaningful learning experiences for their students. Moreover, such models have been described as only accountability tools used to judge teacher ineffectiveness and poor student performance. In gifted programs, such models have been seen to prevent the constructivist approach to learning, namely that students must make meaning for themselves rather than have it imposed from the outside. Thus scope and sequence development in gifted curriculum has not been common. However, as we examine the importance of linking gifted education to content-based areas of the curriculum, it is critical that we consider the role of scope and sequence of learning experiences in that process.

The scope and sequence model developed in this project serves several important functions, each of which is reviewed briefly below.

1) The scope and sequence model provides a linkage from the broad concept papers and generalizations to the technology of school curriculum. It provides a scaffolding for these concepts that allow educators to engage meaningfully in the process of curriculum development around a set of scientifically valid ideas.

2) The scope and sequence model also provides a way to represent differentiation for high ability learners through the statement of learner outcomes. Currently, in most contexts expectations for all learners are the same. This model attempts to show more advanced, complex, and sophisticated outcomes for high ability learners at earlier stages of development. Yet it also demonstrates how a single set of outcomes for all can be made sophisticated and advanced for high ability learners, but remain constant for other learners.

3) The scope and sequence model provides a way for readers to get a snapshot view of the key emphases of the project in direct relation to each other. The model also provides a way to traverse the elements individually through the continuum of K-8 levels.

4) The scope and sequence further emphasizes the importance of students' learning science as opposed to merely being exposed to it, with particular specified outcomes around that learning at the grade level clusters of 2, 5, and 8. As a device to emphasize learning, it also provides the basis for developing an assessment protocol to measure the extent of the intended science learning.

5) In addition to these worthy purposes, this scope and sequence model also served as part of the teacher training effort during the summer in order to enable teachers to make the connections and applications necessary to engage in the unit development process. Thus it served as the organizing structure for guiding unit topic selection, providing key ideas about systems to be taught in each unit, providing key scientific processes to be taught, and emphasizing the need to identify a problem of significance, to infuse technology, and to use scientific habits of mind, critical thinking, and metacognition in the delivery system for each unit.

These five purposes then undergirded the scope and sequence development. As the project evolved over the 18 months of its duration, the fundamental model shifted to reflect those emphases most used by teachers in the unit development process: the concept outcomes, the scientific process outcomes, and problem-based learning approaches. These unit adaptations of the original model are also represented in this document.

The Process for Scope and Sequence Development

Stage I (October - June)

The project staff used the definitional structure of scope and sequence emanating from the curriculum work of VanTassel-Baska (1992). Scope refers to the extensiveness of the curriculum experiences across a predetermined period of time. The determination of scope hinges on the value attached to what is to be taught. For purposes of the project, the scope of the curriculum was limited to the concept of systems in science but applied in a variety of ways to other areas of learning. Sequence refers to the order in which the desired curriculum experiences will be taught and learned. For purposes of the project, the order was established around the progression of knowledge, skills, and concepts from kindergarten through grade 8.

A review of existing scope and sequence documents in science education at the K-8 levels was conducted. Specific documents reviewed included the California Framework, the Virginia Standards of Learning, and the Illinois State Learner Outcomes. These documents were used 1) to determine important components of a scope and sequence document that educators would expect to see, 2) to determine what reasonable outcomes for average learners were at these stages of development in science, and 3) to decide if additional features would be useful in framing out the parameters of science curriculum for the teachers who would use it as a guide for unit development. Based on the review of these guides and relevant materials from Project 2061 and the National Science Teachers Association (NSTA), the following elements were judged important to represent in the scope and sequence model:

Concept Outcomes

The concept of "systems," was selected as the appropriate one to use for unit development based on its ease of application to various areas of science as well as to other areas of study. Integral to understanding this concept, were a set of generalizations derived from the concept paper on systems. These generalizations were:

- All systems have identifiable elements and boundaries
- All systems experience input and provide output
- Systems are characterized by the nature of their internal interactions
- Systems display predictable behaviors

These generalizations were then converted into outcome statements for use at each grade level cluster. The concept outcome statements for grades 3-5 and 6-8 were extended and made more complex in order to represent progressive development in the concept. Moreover, undergirding the notion of concept development in science systems was the idea that at each successive stage of development students would encounter more sophisticated systems. For example, an electrical system is more complex than a simple cell system, and therefore was treated at the 3-5 level while a simple cell system was used as an illustration of the generalizations at the K-2 level.

Content Applications (Knowledge Footprints)

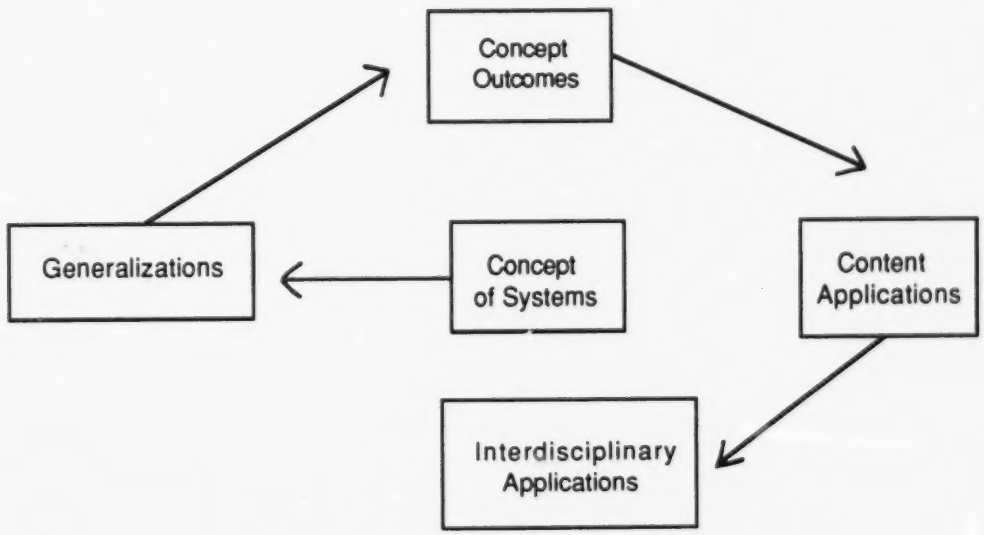
For each grade level cluster, specific applications to content in science were made. Specifically, there was an example provided in the biological sciences, the physical sciences, and the geological sciences that followed the concept outcome model noted. By providing these application to the major domains of science, the scope and sequence illustrates how the more abstract concept of systems can be translated to a very concrete level of application. These applications also illustrate how science content may be taught within the broader concepts of science.

Interdisciplinary Applications

For each grade level cluster, applications to at least two other areas of study beyond science were explored using the same concept outcomes for systems as the guiding model. Thus at K-2, students study social systems and number systems; at 3-5 students study cities as systems and language as a coding system; at 6-8 students study political and economic systems. These interdisciplinary connections are also stated in outcome language. (Figure 1 below illustrates the progression of treatment of the concept of "systems" in this scope and sequence.)

Figure 1

The Path of Concept Development



Scientific Process

Also fundamental to the development of the scope and sequence model in science is the key element of scientific process. In the development of these outcomes, the science concept paper entitled "Nature of the Scientific Process" was used as a framework. Thus the fundamental steps in the process were defined as:

- Learn a great deal about your field
- Think of a good (interesting, important, and tractable) problem
- Decide which experiments/observations/calculations would contribute to a solution of the problem
- Perform the experiments/observations/calculations
- Decide whether the results really do contribute to a better understanding of the problem
- Communicate your results to as many people as possible

From these basic steps, the following generic outcomes were generated.

- Explore a new scientific area.
- Identify meaningful questions within that scientific area
- Address scientific questions in the subject area directly in one of several ways:
- Demonstrate good data-handling skills
- Analyze any experimental data as appropriate
- Evaluate their results in the light of the original problem
- Use their enhanced understanding of the area under study to make predictions about similar problems whose answers are not yet known to the student
- Communicate their enhanced understanding of the scientific area to others

It was felt that high ability students at all levels would be able to apply these processes to ever increasingly more complex investigations.

Problem-Based Learning

Another key element that provided the superstructure for later unit development was problem-based learning, an approach to problem solving that is grounded in focusing on a real ill-structured problem that can be subjected to various stages and types of investigation. Outcome statements were generated to delineate the various stages of the process that the learner must negotiate in order to move towards problem resolution.

Technology

The technology outcomes were viewed as important in developing student understanding of science through learning to use the tools of science; namely those of technology. The interrelatedness of science and technology was readily acknowledged in the nature of materials reviewed for the project. Thus the early and consistent use of relevant technology in doing science was emphasized. Particular tools cited for use at K-8 levels were: computing tools, word processing tools, data analysis tools, data collection tools, and the light microscope.

Instructional emphases: ***Within the scope and sequence model, the following elements were seen as critical for teachers in their instructional planning. Thus each set of student outcomes is accompanied by a corresponding set of teacher behaviors necessary to emphasize the desired outcome.***

Scientific Habits of Mind

This element of the scope and sequence provides a set of outcomes that delineate the attitudes and beliefs of scientists about their work. They closely parallel and complement the major steps in the scientific process but provide an attitudinal perspective on doing science as described by Welch (1986).

Critical/Productive Thinking Skills

This component was viewed as an important one to integrate into the scope and sequence model. Because so many thinking skill models have been used in gifted education, it was important to select a set of critical thinking skills that matched well with the scientific thinking model that is embedded in the scientific process. The model selected can be taught at all levels by varying the complexity of the task demand. Thus students in grade two might predict outcomes for their own experiment on plant growth, while at grade 8 they might predict outcomes from an experiment on genetic manipulation.

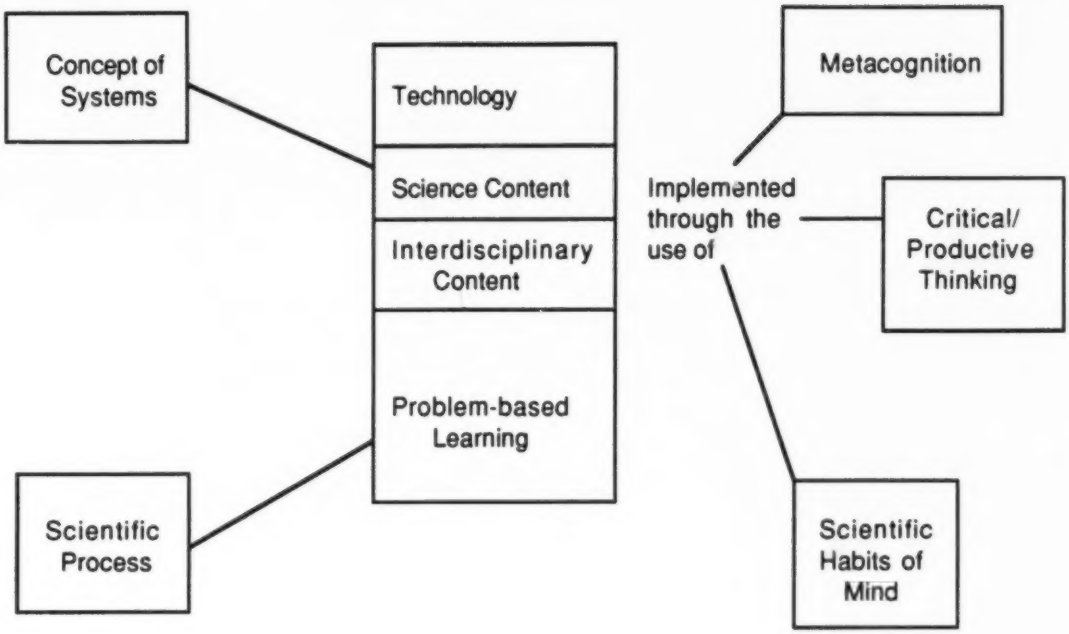
Metacognitive Skills

This component was selected as a culminating instructional emphasis within the scope and sequence model because of its important role in students' taking responsibility for their own learning. Metacognitive strategies provide a set of processes that allow students to improve study habits, to engage in more efficient problem-solving, and to provide a process for independent work in science. The fundamental skills of planning, monitoring, and assessing one's work are a critical complementary emphasis to the other elements of teaching and learning science.

These nine elements then shaped the following scope and sequence model. The elements are presented in a linear fashion even though there are important relationships among them. These relationships were originally perceived to be an interaction of the concept of systems with the scientific process as applied to science content and interdisciplinary content, integrated with technology and problem-based learning, and supported by the instructional strategies of metacognition, scientific habits of mind , and critical thinking. Figure II portrays these relationships among curriculum features.

Figure II

Curriculum Features



Stage II (July-November)

At the initial stage of scope and sequence development, each of the scope and sequence elements was treated with somewhat equal importance. As the project evolved, two sets of student outcomes became the primary emphasis for the units, particularly as outcomes influenced assessment of the units. These two primary areas were the concept outcomes in a reorganized set and the scientific process outcomes. Other outcome categories from Stage I of the process became curriculum unit components that guided the unit revisions in-house but were not used in any formalized approach to assessing student learning. The outcomes used to assess student learning in the units were:

Generic Concept Outcomes

Students will be able to:

- Describe the important elements of the system
- Delineate the boundaries of the system
- Describe input into the section
- Describe output from the system
- Identify elements, boundaries, inputs, outputs (and interactions) as parts of 'systems'
- Use the terms describing systems to identify the components of the system under study
- Transfer knowledge about the system studied to other systems

Generic Research Outcomes

Students will be able to:

- Explore a scientific area.
- Identify a meaningful problem for investigation.
- State an hypothesis.
- Work through a preplanned experiment or demonstration or aid in the development of an experiment.
- Make appropriate observations.
- Create a simple graph or chart. Label diagrams appropriately.
- Record data in appropriate format.
- Analyze experimental data: data tables, graphs.
- Perform appropriate calculations by hand.
- Evaluate experiment results in light of the original problem.
- Make predictions about similar problems.
- Communicate using posters, oral communication, brief lab reports.

Stage III (December - March)

At the final phase of the scope and sequence development process, the generic concept outcomes and scientific process outcomes were translated into specific unit outcomes and assessment indicators provided for each outcome. One example of this final translation process of the model may be seen in the Chesapeake Bay unit for fifth grade (see Figure III).

Figure III: Scope and Sequence for Systems

Components	Grade 6-8	Bay Unit	Assessment
	(repeat outcomes for 3-5)	Identify an ecosystems Bay ecosystem web and its components.	
Systems: Parts		Describe systems and their attributes.	Paper ecosystem
	Analyze the regulatory mechanisms that control the behavior of the system	Describe the natural regulatory mechanisms Lesson in the Bay ecosystem.	Log activity: Systems
	Describe why and how input and output are critical to a system.	Describe the input and output of the Bay ecosystem and their contributions to the system.	Paper ecosystem
Systems: Actions	Describe the independent and compound effects of interacting inputs.	Describe how inputs combine to form pollutants.	Fertilizer experiment Log reaction to fertilizer problem
		Describe how pollutants affect the Bay system, especially its output.	Log reaction: algae experiment;fertilizer experiment.
	Describe the different types of regulation in the system using appropriate terminology.	Describe the natural and political regulations on the Bay and describe their functions as parts of the system.	Ordinances Paper ecosystem.

	Create a system using all components and including appropriate regulating mechanisms.	Write an ordinance regulating Bay pollution and describe the effects their regulation will have on the Bay ecosystem and other systems.	Ordinance; evaluation of the ordinance; first and second order effects chart.
Systems: Advanced Understanding		Describe their ordinance as a system, including all parts.	Log reaction: ordinance
	Explain the uses and limitations of the system under study.	Describe how government systems help and hinder Bay life.	Log reaction: ordinance
	Given two potentially interacting systems, identify how the two interact; describe differences in effect of input on the two systems; describe how the two can work together or in conflict.	Describe the impact of human social systems as they interact with an ecosystem.	Log reaction: ordinance Log reaction: ethical appeals
		Analyze the interaction of chemical systems within an ecosystem.	Biotic-Abiotic Element Interaction Chart
		Work within the framework of systemic interactions to resolve a problem concerning the impact of society on the environment.	Ordinance; evaluation of the ordinance
Research: Exploration	Explore a complex science issue.	Analyze a natural system to determine its relationship with other systems.	Bay web
	Discriminate between central and ancillary problems to research.	Identify research issues associated with problem.	Student-developed experiments
Research: Problem Finding	Breaks large questions into component questions.	Prioritize the agenda for solving the problem.	In-class decisions about which questions to investigate

Research: Experimentation		Analyze the Bay problem and identify, design and conduct an experiment to clarify issues or test assumptions about the source of pollution.	Algae experiment Water flow experiment Fertilizer experiment
	State limitations of the experimental design and results.	State limitations of data they gather about chemical properties and the results derived from the experiment.	Lab reports Log reactions to experiments
	Can name and describe the steps in the experimental process.	Identify the components of an experiment.	Experiment Planning Sheet Lab Report
	Initiate use of safety procedures.	Apply proper safety procedures when working with chemicals (goggles, gloves).	Teacher observation. Experiment Planning Sheet
Research: Data Handling	Record descriptive observations about data.	Measure physical and chemical properties of water with accuracy and with proper equipment.	pH experiment data sheet Water ion data sheet
Research: Data Analysis	Create and label a detailed diagram.	Create a diagram of the ecosystem of the Bay.	Paper ecosystem
	Subject data to appropriate statistical tests.	Perform appropriate manipulations with numerical data during experiments.	SAV survey data summary Water ion data summary
	Perform appropriate calculations by hand, calculator, or computer.	Use calculators to calculate averages.	SAV survey data summary; Water ion data summary.
Research: Evaluation; Subsequent Predictions	Generate 2 or more alternative interpretations of the data; defend the more valid interpretation.	Transfer experiment results to application in the context of the problem.	Log reactions to experiments

	Generate questions which are stimulated by the results of the experiments.	Connect the laboratory experiences of pure science to the real world experiences of applied science through the solution of the unit problem.	Transfer of pH testing exploration and pH testing of pond water
Research: Communi-cation	Present results of an experiment in a format similar to scientific meetings.	Present results in appropriate format during final unit activity.	Ordinance reports Bay Fest presentations
	Generate a formal lab report.	Produce a formal lab report based on water sample experiments.	pH lab report Water ion lab report

Interpreting the Scope and Sequence of Learner Outcomes for High Ability Learners

The scope and sequence model was designed to depict a systematic pathway to becoming knowledgeable and skillful in the context of the scientific concept of systems. The model details a progression from simple to complex skills and understanding. The outcomes were designed to provide both a basic background in content and skills and to provide other, more complex outcomes for high ability students. Two ways we differentiated within the outcome framework for high ability students were:

1) By varying the level of the outcome. Each of the outcome statements varies in the degree of difficulty. For example, "create a model of selected organ systems" is more demanding than "understand the functions of the organ system." High ability learners at 3-5 levels may be ready to focus on the more advanced outcome earlier than other students.

2) By varying the sophistication of the content. Interpretation of a simple chart is easy; interpreting and comparing several charts or charts with many different and interacting variables is more difficult. A teacher can vary the degree of sophistication to make a single outcome more complex for high ability students.

Placement of the outcomes at different grade levels was determined based on two factors: the stage at which the skill or idea could be introduced at a developmentally appropriate level for most high ability students and the logical development of a skill sequence. Thus, although the outcome "identify how different intervening variables would change data" is presented at grades 3-5, suggesting that this may be the optimal time for the introduction of this skill, it is not meant to imply that it is the only time instruction about intervening variables should occur.

Also, placing an outcome at a particular grade level does not mean that all lessons or all science units have to address that outcome, only that the outcome should be mastered by the end of that grade sequence. Not all outcomes can be achieved through all knowledge footprints. So if an outcome for grade K-2 is "label diagrams appropriately," teachers should not feel compelled to include diagrams in every science unit. That would, in fact, fly in the face of the philosophy of this project--that science instruction should emulate real science. Instead, while planning the curriculum, teachers should be sure to include some unit of study or experimental procedure in which the creation of diagrams is a natural outgrowth of the study.

Despite our desire to make science instruction look and feel like "real science," we cannot ignore that school science and science work are different. Part of the role of schools is to instruct students in the skills which we eventually come to think of as naturally occurring for professional scientists. For that reason, some of the outcomes included may seem a little forced or unnatural. This is especially true about the outcomes in the section "Abstract Understanding About Systems" where the skills are all associated with the ability to describe and operate on the overall concept of systems instead of on the specific application of systems theory to a specific system.

Learner outcomes then provide a basis for assessing student learning at these requisite levels of experience. Students would be assessed in their understanding of the concept of systems in its various applications at the end of grades 2, 5, and 8. Authentic assessment protocols would need to be developed for each stated outcome. So, for example, the outcome from grades 3-5 "describe the output from the system and evaluate the impact of the system on the outside world" would require students to undertake an activity that challenges them to perform that operation, given a system with which they are unfamiliar.

Systems: A Scope and Sequence

I. Concepts

The outcome statements for grades K-8 reflect a continuum of advanced learning and sophistication regarding the concept of systems. The clustering of outcomes by grade level reflects an arbitrary determination of minimum expectations for high ability learners.

A. Grades K-2

For a given system, the student will be able to:

--Describe the important elements of the system
--Delineate the boundaries of the system
--Describe input into the system
--Evaluate its effects on the system
--Describe output from the system
--Evaluate the impact of the system on the outside world
--Analyze important interactions among system elements that give rise to overall system behavior

B. Grades 3-5

For a given system, the student will be able to:

--Describe the important elements of the system
--Delineate the boundaries of the system
--Describe input into the system and evaluate its effects on the system
--Describe output from the system and evaluate the impact of the system on the outside world
--Analyze important interactions among system elements that give rise to overall system behavior
--Analyze the regulatory mechanisms that control the behavior of the system

C. Grades 6-8

For a given system, the student will be able to:

--Describe the important elements of the system
--Delineate the boundaries of the system
--Describe input into the system and evaluate its effects on the system
--Describe output from the system and evaluate the impact of the system on the outside world
--Analyze important interactions among system elements that give rise to overall system behavior
--Analyze the regulatory mechanisms that control the behavior of the system

II. Content Applications (Knowledge Footprints)

The student outcomes in this section are directly related to the systems concept outcomes listed in Section I. For clarity, the relevant systems outcomes are listed in italics after each knowledge footprint outcome.

A. Grades K-2

1. Biology

a. Animal communities

For a small animal community, such as an ant farm, the student will be able to:

--Identify the different members of the community (workers, the queen, soldiers, eggs, larvae, and so forth) (*elements*)
--Analyze the interactions that occur among the different members of the community (*interactions*)
--Understand the major tasks of the community (reproduction, defense, feeding, nest-building, cleanup, and so on) (*interactions, input, output*)
--Analyze the ways in which these tasks are performed (and thus the ways in which each caste of ant contributes to the maintenance of the colony as a whole) (*interactions, input, output*)
--Relate their detailed understanding of the functioning of this small animal community to the functioning of other animal communities, including human communities (*interactions*)

b. Small ecosystem:

For a small ecosystem (such as a schoolyard, garden, or self-supporting aquarium or terrarium) the student will be able to:

--Identify the macroscopic organisms present (*elements*)
--Describe the physical characteristics of the terrain occupied by the ecosystem (*elements, boundaries*)
--Identify instances of symbiotic interactions (parasitism, mutualism, and commensalism) among the different kinds of organisms in the system (*interactions*)
--Describe the niches of some of the most interesting organisms present (*elements, interactions*)
--Comprehend the concept of food chains (*interactions*)
--Identify the components of some of the food chains in the small ecosystem (*interactions*)

--Describe input into the system (sunlight, rain) and analyze its effects on the system (*input*)
--Describe system output and analyze its effects on the outside world (*output*)

2. Earth Science

a. Local weather

The student will be able to:

--Identify important elements common to all weather phenomena (wind, water, etc.) (*elements*)
--Measure important weather variables (temperature, barometric pressure, humidity, windspeed) (*elements*)
--Record the daily changes in the weather (*elements*)
--Describe the characteristics of important weather phenomena (*elements, input, output*)
--Identify the weather phenomena that they measure/observe themselves (*elements, interactions*)
--Predict future local weather using weather forecast information (*interactions, output*)
--Analyze large-scale weather trends using weather maps (*interactions, output*)

b. Local geology

For a small but interesting local site (such as a roadcut or streambed), the student will be able to:

--Identify the important geological components present (for example, water, soil, rock) (*elements*)
--Describe the most obvious geological processes that are occurring at the site (for example, erosion, the deposition of sediment, the movement of rocks down a streambed) (*interactions*)
--Describe the ways in which biological elements (such as lichens or tree roots or humans) affect the geology at the site (*input, interactions*)
--Describe the ways in which the geology of the site affects other systems, such as the local ecosystem (look at where plants grow and where they don't; look at the effects of streambank erosion or flooding on the organisms present) (*output, interactions*)
--Record seasonal variations in the geological processes taking place at the site (*interactions, input, output*)

c. Observational astronomy: the solar system and the universe

The student will be able to:

--Identify the important elements of our solar system (*elements*)
--Describe the motion of the planets around the sun (*interactions*)
--Describe the motion of the Moon around the Earth (*interactions*)
--Explain seasonal changes in terms of the movement of the earth around the sun (*interactions*)
--Describe, predict, and explain the phases of the moon (*interactions*)
--Describe and predict the height of the sun at noon at different times of year (*interactions*)
--Describe the observable differences (as observed with the naked eye, from the surface of the Earth) between the planets of our solar system and the stars (planets don't twinkle; planets change their position relative to the stars, but the stars don't change their positions relative to each other) (*elements, interactions*)
--Describe and explain lunar and solar eclipses in terms of the position and movements of the Sun, the Earth, and the Moon (*elements, interactions*)

3. Physical Science

a. Simple machinery

For an interesting piece of working, nonelectrical, noncomputerized machinery (such as a wind-up clock or an old camera), the student will be able to:

--Describe the function of the machinery as a whole (*input, output*)
--Disassemble the machine with appropriate tools (*elements*)
--Identify the different kinds of small parts that make up the machine (screws, pins, gears, rollers, levers,etc.) (*elements*)
--Describe how each small machine part works (*elements, interactions*)
--Describe the functions of the parts of the machine relative to the action of the machine as a whole (*elements, interactions, input, output*)

b. Simple physical/chemical systems

For a very simple physical or chemical system, the student will be able to:

--Describe the physical and chemical components present in the system (for example, a beaker and water) (*elements, boundaries*)
--Identify important input into the system from the outside world (for example, heat energy from a hot plate) (*input*)

--Describe the effects on the system of input from the outside world (for example, the water heats up)(*input*)
--Measure the effects on the system of the input from the outside world (for example, measure the temperature of the water repeatedly as the hot plate heats it; measure the mass of the system before and after heating) (*input*)
--Describe important system output (for example, the system releases steam upon heating) (*output*)
--Generalize from their analysis of the system's behavior (for example, they should be able to explain why people put pans of water on the radiator in the winter when the indoor humidity is uncomfortably low) (*impact*)

B. Grades 3-5

1. Biological Science

a. Organ systems and organisms:

The student will be able to:

--Understand the functions of the different organ systems that make up the human body (*elements, interactions, input, output, regulation, boundaries*)
--Compare and contrast the structures and functions of human organ systems with those of other species (*elements, interactions, regulation, input, output, boundaries*)
--Conduct noninvasive experiments in basic human physiology (*elements, interactions, regulation, input, output*)
--Creat a model of the actions of some of the organ systems (effects of HCl on typical stomach contents, for example) (*elements, interactions, regulation, input, output*)

b. Local ecology

For a major local ecosystem (for example, a pond, woodland, stream, farm, or park),the student will be able to:

--Identify as many of the organisms present as is reasonable (*elements*)
--Map the physical characteristics of the terrain occupied by the ecosystem (*boundaries*)
--Map the distribution of a representative sample of the different types of organisms in the ecosystem over the terrain occupied by the ecosystem (*elements, boundaries*)

--Recognize important input into the system (sunlight, rain) and evaluate its effects on the system (*input*)
--Evaluate the importance of the system to the outside world (*output*)
--For the representative organisms listed above, analyze the niche of each organism and determine how its structural and behavioral adaptations enhance its survival in that niche (*elements, interactions, regulation*)
--Analyze the role of humans in the ecosystem (*elements, interactions*)

2. Earth Science

a. Solar system

The student will be able to:

--Describe the physical characteristics of the planets in our solar system (*elements*)
--Compare and contrast surface conditions for each of the planets and their moons (gravity, temperature, presence of an atmosphere, etc.) (*elements*)
--Relate the present-day characteristics of the major structures in the solar system to what is known of their evolutionary history (ffor example, the origin of the moon, the formation of asteroid belts, and so on) (*elements, boundaries, interactions*)
--Evaluate the planets and their moons as possible sites for human colonization in the future (*elements, interactions, input, output, regulation*)

c. Lab and field geology

For a local site of geologic interest, the student will be able to:

--Identify the most common minerals through standard classification methods (including simple chemical tests, when appropriate) (*elements*)
--Identify different types of geological materials (silt, shale, aggregate, and so on) (*elements*)
--Map the distribution of the different minerals and different types of geologic materials present at the site (*elements, boundaries*)
--Relate the materials present in the site of geologic interest to the geological processes that are operating at the site or that operated at the site in the past (for example, gravel pits are full of many different types of rocks; how did they get there?)(*elements, boundaries, interactions, regulation, input, output*)

3. Physical Science

(Note: this section may be augmented by LEGO/Logo work)

a. Properties of electrical circuits

The student will be able to:

--Describe the properties of a variety of circuit elements, including small light bulbs, wires, resistors, capacitors, and batteries (*elements*)
--Use the unit systems that describe circuit behavior (amperes for current, volts for electrical potential energy, watts for power) (*elements*)
--Construct circuit diagrams using appropriate symbols for all circuit elements (*elements, boundaries*)
--Use appropriate measuring devices (ammeters and voltmeters) to investigate circuit behavior(*elements, interactions, input, output, regulation*)
--Investigate the effects of alternative arrangements of circuit elements (complete vs. incomplete circuits, arrangement of resistors in series rather than in parallel, and so on) (*elements, interactions, boundaries, regulation, input, output*)
--Describe the structure and function of a simple regulatory circuit (for example, a thermostat)(*elements, interactions, regulation, input, output*)
--Construct simple circuits designed to perform specified functions (*elements, interactions, boundaries, regulation, input, output*)

b. Electrical machines

For an interesting piece of working electrical machinery that does not consist entirely of computer chips (such as a telephone or an electric clock), the student will be able to:

--Dissect the machine and identify the different kinds of small parts that make up the machine (resistors, capacitors, printed circuit boards, speakers, wires, etc.) (*elements*)
--Describe the function of the machinery as a whole (input, output)
--Match each of the circuit elements on a wiring diagram of the machine with its corresponding physical circuit element in the machinery (*elements, interactions, boundaries*)
--Relate the actions of some of the major pieces of the machine to the function of the original piece of machinery (*elements, interactions, input, output, regulation*)

c. Kitchen chemistry

Every chemical reaction is a system and can be analyzed as such. The focus on the kitchen rather than the laboratory is important, both because the reagents used are more familiar to most students than are most laboratory chemicals, but also for simple reasons of safety. A student that tastes vinegar is less likely to be seriously affected than one who tastes concentrated HCl.

The student will be able to:

--Describe the physical and chemical components present in a kitchen chemistry system (for example, cut fruit in a glass bowl) (*elements, boundaries*)
--Identify important input into the system from the outside world (for example, air) (*input*)
--Describe the effects on the system of input from the outside world (the fruit turns brown) (*input*)
--Measure the effects on the system of the input from the outside world (determine the rate at which the browning occurs) (input)
--Describe important system output (*output*)
--Design experiments that will test the system's behavior (for example, what happens if you add lemon juice to the system? if you exclude air? if you heat the system?) (*elements, interactions, input, output, regulation*)
--Generalize from their analysis of the system's behavior (adding an acid to cut fruit slows oxidation)(*elements, interactions, regulation, input, output*)

C. Grades 6-8

1. Biological Science

a. Cell biology

The student will be able to:

--Describe the appearance and behavior of a variety of unicellular organisms (*elements, input, output*)
--Describe the structures of a variety of animal and plant tissues in terms of the appearance and arrangement of their cells as observed under the light microscope (*elements*)
--Prepare stained tissue specimens for light microscopy
--Compare and contrast the structural features of different cell types as viewed under the light microscope (*elements*)

--Describe the functions of the subcellular structures visible in stained tissue sections under the light microscope (*elements, interactions, regulation, input, output*)
--Relate the structures of different cell types to the functions of those cells (*elements, interactions, regulation, input, output*)

b. Genetics

The student will be able to:

--Predict the segregation of alleles in a monohybrid cross, using the laws of probability (*elements, interactions*)
--Predict the segregation of alleles of unlinked genes in a dihybrid cross, using the laws of probability (*elements, interactions*)
--Predict the phenotype and genotype distributions in the progeny of a dihybrid cross involving unlinked genes, using the properties of dominant and recessive alleles (*elements, interactions, regulation, output*)
--Describe representative instances of Mendelian inheritance in man (blood type, for example)(*elements, interactions, regulation, output*)
--Analyze a human pedigree to follow the inheritance of a particular human phenotype (for example, the Hapsburg lip) (*elements, interactions, regulation, output*)
--Analyze human pedigrees to predict whether a human Mendelian trait is recessive or dominant (*elements, interactions, regulation, output*)
--Using pedigree analysis, predict whether a human Mendelian trait is sex-linked (hemophilia in the royal houses of Europe...) (*elements, interactions, regulation, output*)

c. Human reproduction and embryonic development

The student will be able to:

--Describe the structures and functions of the components of the human reproductive system (*elements, interactions, regulation, output*)
--Describe the menstrual cycle and its relationship to human fertility (*elements, interactions, output*)
--Evaluate the relative effectiveness of each of the available forms of contraception (*elements, interactions, regulation, input, output*)
--Analyze the reasons for the heightened sensitivity of the fetus to such environmental insults as alcohol and drugs, using an understanding of the major steps in human fetal development (*elements, interactions, regulation, input, output*)

--Compare and contrast the process of human embryonic and fetal development with development processes in other organisms (*elements, interactions, regulation*)
--Describe the major features of human child development from babyhood through adulthood (*elements, interactions, regulation*)

d. Planetary ecology (a combination of biological science, physical science, and earth science topics):

The student will be able to analyze a major anthropogenic problem and its effect(s) on relevant terrestrial ecosystem(s). This should be done as a part of a problem-based learning experience. The example below illustrates one such problem.

Background for the Problem

The problem in this example is that of nuclear contamination. Since the Manhattan Project began in the1940s, humans have been generating large quantities of radioactive waste. It has generally not been handled well, both due to lack of strictly enforced government regulations and to its intrinsic nature (chemical danger of many waste products, long half-lives, high volume of both high and low-level radioactive trash, and so on). Thus, many sites which have been used to process radioactive material are heavily contaminated, and their contamination problems threaten surrounding areas (for example, the Rocky Flats nuclear weapons plant in Colorado; the weapons plant in Fernald , Ohio; the Oak Ridge site in Tennessee; the Savannah River nuclear weapons facility in Georgia; the Three Mile Island reactor in Pennsylvania, and so on.) In addition, the landfills that accept low-level radioactive waste are filling up and no new landfills have been opened; also, there is still no storage facility available for high-level waste, such as that from the cores of nuclear reactors.

Introducing the Problem to the Students

The students need a human being who has a problem that they can identify with. The problem could be introduced to the students either by someone playing the role of the affected individual, or by use of written material, such as a simulated newspaper article.

For the Rocky Flats site, possibilities might include:

--The doctor, Carl Anderson, who noticed clusters of childhood leukemia cases in areas adjacent to the Rocky Flats nuclear weapons facility and raised the alarming possibility that contamination of the childrens' environment by Rocky Flats was responsible for their disease

--A parent of a child with leukemia in Broomfield, Colorado
--A water quality manager working for the city of Broomfield who is worried about possible radioactive contamination of the town water supply
--A government inspector who notices that significant amounts of plutonium are missing from the Rocky Flats inventory
--A resident of Denver whose house backs up on the railroad tracks used to transport nuclear waste from Rocky Flats to the dump site in Idaho
--The governor of Idaho, Cecil Andrus, who is under political pressure to refuse all radioactive waste generated outside the state

Once presented with the problem, students will:

--Be motivated to explore the problem further because of their identification with the affected individual
--Find information relevant to the further definition of the problem and to the generation of possible solutions of the problem . A very partial list of questions that could be explored during the solution of this problem would include:

What is radioactivity?
How is it measured?
Is it dangerous?
What effects does it have on people?
Can it cause cancer?
How much exposure does it take for the various biological effects to blow up?
How do we store hot waste now?
Are there problems with current storage technology?
How could we design a safe storage site?
How long does it take for radioactive material to decay?
What is half-life?
What do they do at Rocky Flats?
What is the safety record for the Rocky Flats plant?
Have there been any documented spills or other inadvertant releases of radioactive material from the plant?
Do we need the Rocky Flats plant?
Is the water in Broomfield safe?
Are there other possible sources of radioactive contaminants in the immediate area besides the Rocky Flats facility?
Why does Cecil Andrus want to stop accepting radioactive waste generated outside of Idaho?

(Note: the exact questions brought up during the course of the problem-based learning process will differ depending on the afflicted individual picked initially: for example, Cecil Andrus

would not care much about the Broomfield water supply, so questions relevant to Broomfield might not be picked for his problem)

--Periodically redefine the problem as their work progresses. Information will be brought into class as it is gathered and the students and teacher will discuss its relevance, the possible new questions its existence generates, and any other new approaches to the solution and definition of the problem that are indicated.
--Generate possible solutions to the problem
--Evaluate the cost and efficacy of the possible solutions that they generate
--Test aspects of some of their solutions experimentally. For this problem, students could:

(1) Investigate the movement of water through geological materials of different chemical compositions and particle sizes to better understand the geological conditions necessary for proper long-term storage sites)

(2) Investigate the radioactive shielding properties of materials such as lead, plastic, and water for different forms of radiation; examine the effect of altering shielding material thickness as well as composition

(3) Examine the biological effects of radiation. For example, the student could analyze the effects of irradiation on seed germination and growth and on plant appearance or experimentally determine the effects on the mutation rate of fruit flies exposed to different levels of radiation.

(4) Write a computer program that will allow the student to calculate the amount of time required for different amounts of different radioactive materials to decay to a safe level

--Relate the situation in the problem to situations that are closer to home. The nuclear waste issue has local implications almost everywhere. Local organizations to check with would include:

(1) The local hospital: find out how much waste they generate and where it goes.

(2) The local power company: is there a nuclear plant nearby?

(3) Local industry: do they generate hot waste and/or store radioactive materials? What do they do with their waste, and what is corporate policy on storage and handling of radioactive

materials? Start with the P. R. people...then look at back files of the local paper and talk to local officials about the industry's record.

(4) Government agencies: the EPA, the Bureau of Mines, and the U. S. Geological Survey will all have information about aspects of this problem that are important locally, as will the state water quality people and the state geological survey.

(5) Environmentalists are also very interested in this issue. Organizations to contact include The Sierra Club, The Environmental Defense Fund, and Greenpeace.

Outcome statements related to the systems concepts outcomes in Section I of this scope and sequence document can also be listed for this problem. They are:

(1) Boundaries: The student will be able to delineate the boundaries of the system that emerges from his definition of the problem.
(As the possible problems that can be defined by students given this situation can differ, the boundaries of the system defined by the problem will also differ. The boundaries of such a problem system could be defined as the physical boundaries of the Rocky Flats plant and any areas affected directly by its waste, or as the boundaries of the American political system, because nuclear waste is ultimately as much a political as a scientific problem.)

(2) Elements: the student will be able to clearly list the elements of the system that are relevant to the problem he has defined. (In this example, elements common to most of the possible scenarios would include the physical nature of the Rocky Flats plant, the human elements who manage and work at the plant, the political elements that support and oppose its operation, the residents of areas adjacent to the plant, the residents of areas adjacent to the nuclear waste repository in Idaho that receives the waste from Rocky Flats, and so on. Different scenarios will emphasize the roles of some of these elements differently, of course.)

(3) Interactions: the student will be able to describe the interactions between system elements that are most important for the function of the system. (For this sort of problem, many different interactions could be explored in depth, from the interactions that characterize the U. S. military-industrial complex to the interactions that occur among different chemical constituents of high-level radioactive waste.)

(4) Regulation: the student will analyze the regulatory mechanisms that affect system behavior. (In this case, the student could look at the rationale for the existence of the Rocky Flats plant and for its level of activity, and explore factors that would affect society's view of its necessity: for example, fear of the Russians and the arms race vs. local safety concerns and the pressure for disarmament; students primarily interested in waste disposal could identify and explore the conflicting interests that are currently holding up the creation of a new long-term storage facility for high-level waste. The precise regulatory interactions studied, of course, will depend on the problem defined by the students.)

(5) Input/ output: the student will identify input important to the system and output from the system that affects the outside world. (Given the definition of the system's boundaries described by the student, input and output and their effects on the system and the outside world should be considered. For example, if the system is the city of Broomfield, its population, and its water supply, important input would include groundwater contaminants from Rocky Flats; important output would include political pressure put on the Department of Energy by the citizens of Broomfield and their elected representatives.)

2. Physical Science

a. Introductory chemistry

The student will be able to:

--Predict the behavior of materials undergoing a phase change (*elements, interactions, output, input, regulation*)
--Describe the physical and chemical properties of the different phases of water (*elements, interactions*)
--Separate simple chemical mixtures (for example, water, salt, sand, and ethanol) (*elements, interactions*)
--Use standard wet-lab chemical glassware and equipment properly and safely
--Make accurate measurements of such quantities as mass, volume, temperature, and pH using appropriate equipment
--Understand the difference between precision and accuracy
- -Use the proper number of significant figures when describing a measurement or performing a calculation

--Understand the chemical properties of acids and bases; handle acids and bases properly and safely in the laboratory (*elements, interactions*)
--Understand and interpret the physical and chemical behavior of simple solutions (*elements, interactions, input, output, regulation*)
--Understand and interpret the formation of precipitates (*elements, interactions, regulation, input, output*)
--Analyze chemical systems in terms of the interactions of their elements with each other and with input from the outside world (*elements, boundaries, interactions, input, output, regulation*)
--Use chemical symbols to describe the reactants and products in their chemical systems; understand how to balance chemical equations (*elements, interactions*)
--Predict the physical and chemical properties of the elements using the periodic table (*elements,interactions, regulation, input, output*)

3. Earth Science

a. Local geology

For a local site of geologic interest, the student will be able to:

--Identify as many of the geologic materials present as possible (*elements*)
--Map the distribution of the different minerals and different types of geologic materials present at the site (*elements, boundaries*)
--Identify chemical processes at the site that are altering its geology (for example, the decomposition of biological materials and soil formation; leaching of surface materials into deeper layers; oxidation of newly exposed rock) (*elements, interactions, regulation, input, output*)
--Model some of the physical and chemical processes important to the site in the laboratory (*elements, interactions, regulation*)
--Analyze the effects of meteorological processes on the site's geology (*input*)
--Analyze the effects of biological processes on the site's geology (*input*)
--Analyze the effects of humans on the site's geology (*input*)
--Make inferences about the site's geological history based on the geologic materials present and their arrangement (*elements, interactions, regulation, boundaries, input, output*)
--Use geologic maps to understand the geology of the site in greater detail (*elements, interactions, boundaries*)

III. Interdisciplinary Applications

Many of the science content applications listed in Section II have interdisciplinary components. Another way to introduce an interdisciplinary focus, however, is to treat systems outside the realm of science in the same way as scientific systems. Some possibilities for each grade level are developed below.

The student outcomes in this section are directly related to the systems concept outcomes listed in Section I. For clarity, the relevant systems outcomes are listed in italics after each outcome.

A. Grades K-2

1. Social Systems

For a small social group of human beings such as a family, the student will be able to:

--Describe the different roles performed by the different members of the social community (*elements, interactions*)
--Analyze the interactions between different members of a social community and the contributions that these interactions make to the overall functioning of the community (*elements, interactions*)
--Analyze the effects of the outside world on the functioning of the small social community (*input*)
--Analyze the impact of the small social community on the outside world (*output*)

2. Number Systems

For a number system (such as whole numbers taught through sets), the student will be able to:

--Describe the function of different numbers in the system (*elements*)
--Analyze the interaction between numbers in the system and the contribution of each to the system (*interactions*)
--Evaluate the effect of introducing other number combinations into the system (*input*)
--Evaluate the effects of the number system on other number systems (*output*) (What would happen if you changed bases?)

B. Grades 3-5

1. Cities as Systems

All cities can be thought of as systems whose elements include both the physical structures and systems present (buildings, roads, parks, sewers, electrical and

gas lines, and so on) and the human components present (individuals, families, neighborhoods, political control systems, schools, businesses, and so on.)

The student will be able to:

--Describe the elements that make up a city (*elements*)
--Understand the functioning of the city as a whole (*input, output*)
--Analyze important interactions among the city's elements that keep the city functioning (*elements, interactions, regulation*)
--Demonstrate the importance of input into the city (food, energy, materials, people) (*input*)
--Analyze city output and its varied effects on the outside world (products, information, people, trash, etc.) (*output*)

2. Language: Codes and Ciphers

The student will be able to:

--Compare and contrast different ways of constructing codes and ciphers (*elements, interactions*)
--Analyze the built-in advantages and limitations of each code and cipher (for example, which of the systems is the easiest to use? The hardest? How easy would it be to decode each system?) (*input, output*)
--Generate and use their own code or cipher (*elements, interactions, input, output*)

C. Grades 6-8

1. Political Systems

The student will be able to:

--Describe the elements that make up each of a number of different political systems (U.S.,Great Britain, China, the Soviet Union) (*elements*)
--Analyze the important interactions that define the behavior of each system (who wields the power and what can they do with it?) (*interactions*)
--Analyze the effects of input from outside the system on the function of the system (for example, how does the system deal with rioting in the streets and how much is it affected by such input?) (*input*)
--Analyze the effects of the system on the outside world (*output*)
--Compare and contrast the features of the different systems that are relevant for the people governed by them (Do the people have significant input into the decisions of their leaders? How repressive is the society?) (*elements, interactions, regulation, boundaries, input, output*)

2. Economic Systems

For a variety of different economic systems (for example, capitalism as practiced in the United States, democratic socialism as practiced in Sweden, command-economy socialism as practiced in the USSR), the student will be able to:

--Describe the important elements of each economic system (*elements*)
--Describe the interactions between system elements that determine the overall behavior of the economy (*interactions*)
--Analyze the interactions of the economy with outside forces (*input*)
--Compare and contrast the ability of the different economic systems to innovate, to provide products and services to the people in each system, and to respond flexibly to internal and external challenges (*elements, interactions, boundaries, regulation, input, output*)
--Analyze the effects that each system has on the world economy as a whole. (*output*)

3. Language as a System

The English language is a system with important elements (grammar, roots, words) which interact to give the language its overall character and utility.

For the English language, the student will be able to:

---Identify the different parts of speech (*elements*)
--Predict the meaning of previously unknown words embedded in a more understandable context, using their understanding of the rules of grammar and the structure of English words; describe the reasoning behind each prediction (*elements, interactions, regulation*)
--Analyze the origins and uses of words that have recently entered the English language (*input*)
--Analyze how English words have been used in foreign languages (*output*)

IV. Scientific Process

The outcomes listed for this element require the student to be able to use the scientific process at each grade level to some extent. At grades K-2 the students would be introduced to all aspects of scientific process, at grades 3-5, they would develop the skills more freely; and at grades 6-8, they would demonstrate mastery in the use of them on a research problem of appropriate complexity.

Grades K-8

The student will be able to:

1. Explore a new scientific area.

2. Identify meaningful questions within that scientific area.

3. Address scientific questions in the subject area directly in one or more of the following ways:

   --Work through a preplanned experiment or demonstration and record the results
   --Design an appropriate experiment, with attention to generation of a testable hypothesis, choice of appropriate variables, and the inclusion of suitable controls
   --Perform an experiment of their own design, using good experimental technique
   --Make and record appropriate observations
   --Perform appropriate calculations, by hand or with a calculator or computer
   --Use appropriate computer simulations to understand the scientific problem better

4. Demonstrate good data-handling skills.
   --Keep a good laboratory notebook
   --Save raw data and reference it in the notebook
   --Keep photographic evidence of otherwise unrecordable data.

5. Analyze any experimental data as appropriate. Analytical skills used could include:
   --making data tables
   --graphing data
   --performing computations by hand, with a calculator, or with a computer, as appropriate

6. Evaluate their results in the light of the original problem. Answer such questions as:
   --did the hands-on work solve the problem?
   --did the hands-on work suggest new areas for investigation?

7. Use their enhanced understanding of the area under study to make predictions about similar problems whose answers are not yet known to the student.

8. Communicate their enhanced understanding of the scientific area to others. Students will be able to communicate this information in the following ways:
   --an oral report to the class
   --a poster
   --a written lab report

V. Problem-Based Learning

The outcome statements for problem-based learning represent a progression of complexity in the treatment of the problem at the fourth step of evaluation proceeding from primary to middle school levels. *These outcomes were not adopted for later stages of the project.*

A. Grades K-2

When presented with an ill-structured "real-life" situation, the student will be able to:

1. Determine if a problem exists.
2. Create an exact statement of the problem.
3. Generate possible solutions.
4. Evaluate the possible solutions in as many of the following ways as the problem allows:
   a. Distinguish between fact and inference.
   b. Weigh the positive and negative effects of each solution.
   c. Test important aspects of each solution experimentally.

B. Grades 3-5

When presented with an ill-structured "real-life" situation, the student will be able to:

1. Determine if a problem exists.
2. Create an exact statement of the problem.
3. Generate possible solutions.
4. Evaluate the possible solutions in as many of the following ways as the problem allows:
   a. Distinguish between fact and inference.
   b. Weigh the positive and negative effects of each solution.
   c. Perform a cost-benefit analysis.
   d. Create ripple-effect diagrams to look at the repercussions of each solution.
   e. Test important aspects of each solution experimentally.

C. Grades 6-8

When presented with an ill-structured "real-life" situation, the student will be able to:

1. Determine if a problem exists.
2. Create an exact statement of the problem.
3. Generate possible solutions.
4. Evaluate the possible solutions in as many of the following ways as the problem allows:
   a. Distinguish between fact and inference.
   b. Weigh the positive and negative effects of each solution.

c. Perform a cost-benefit analysis.
d. Create ripple-effect diagrams to look at the repercussions of each solution.
e. Test important aspects of each solution experimentally.
f. Develop a policy paper on the problem.

VI. Technology

This scope and sequence explicitly includes technological subjects as content applications: the machines unit, the circuits unit, and the planetary ecology problem-based learning experience all strongly emphasize technology. More generally, though, the most appropriate way to teach students about technology is to have them use it as a tool to accomplish something else. There's no point in just describing marvelous high-tech gadgetry, like an MRI scanner or a scanning tunnelling microscope, to them because:

--They won't have the background to understand how it works
--Without a problem to solve with it, they won't really understand or care about its uses
--It will be outdated information by the time they actually encounter a use for it--ten or so years from the time that they heard about it.

Technology, used as a tool, however, can be marvelous. There is a limited number of items that the children should have direct experience with, as these items will be of great use to them in their study of science. These items are:

--Computing tools: the calculator and the computer.
--Word processing tools: the computer and a good, word processing program.
--Data analysis tools: the computer or calculator and appropriate software packages (graphing programs, curve-fitting programs, spreadsheets, statistical packages)
--Data collection tools: the camera, the camcorder, and the VCR
--Other: the light microscope

Some suggested learner outcomes are listed below. It should be emphasized, though, that the students must be presented with this material in the context of a science experience in which it is useful. The light microscope should be presented only if its use is essential (for example, in the study of cell biology , to help with mineral identification, or in a ecology field study); similarly, the computer as a data analysis tool should be presented only if there are data to analyze.

A. Grades K-2

The student will be able to:

1. Use a calculator to perform computations too laborious to perform by hand.
2. Use a simple word processing program to write lab reports..

3. Use a camera to record information that cannot be preserved otherwise.
4. Use a camcorder to record information that cannot be adequately be captured by still photography.
5. Use a light microscope to observe both wet and dry mounted slides.

B. Grades 3-5

The student will be able to:

1. Use a calculator to perform computations too laborious to perform by hand.
2. Use a computer to perform calculations too laborious to perform on a calculator.
3. Use a simple word processing program to write lab reports.
4. Use a simple spreadsheet program to organize and manipulate data.
5. Use a camera to record information that cannot be preserved otherwise.
6. Use a camcorder to record information that cannot be adequately be captured by still photography.
7. Use a light microscope to observe both wet and dry mounted slides.

C. Grades 6-8

The student will be able to:

1. Use a calculator to perform computations too laborious to perform by hand.
2. Use a computer to perform calculations too laborious to perform on a calculator.
3. Use a simple word processing program to write lab reports.
4. Use a simple spreadsheet program to organize and manipulate data.
5. Use a simple database program to manipulate reference information for a long written report.
6. Use a camera to record information that cannot be preserved otherwise.
7. Use a camcorder to record information that cannot be adequately be captured by still photography.
8. Use a light microscope to observe both wet and dry mounted slides.

Instructional Emphases

This section of the scope and sequence model suggests possible outcomes for students and corresponding behaviors for teachers to use in providing emphasis to these components in the teaching of science. *This section of the scope and sequence model was not used systematically in the later stages of the project.*

VII. Scientific Habits of Mind

Scientific habits of mind represent a combination of cognitive and affective skills and attitudes that need to be fostered throughout the years that students study science. Therefore, the outcomes for this section remain constant from K-8.

The student will be able to:

--Demonstrate scientific curiosity and interest in a scientific problem.
--Demonstrate ideational fluency in formulating science problems and solutions.
--Analyze and evaluate scientific arguments.
--Analyze scientific problems from multiple perspectives.
--Formulate critical questions for given presentations of scientific ideas.

Directly corresponding to the desired outcome behaviors for students are a set of behaviors that teachers must use in order to develop scientific habits of mind in students.

Curiosity

The teacher will:

--Provide a wide variety of materials and experiences for the students to try on their own
--Model curiosity for the students by showing interest and enthusiasm for new ideas and experiences

Creativity

The teacher will:

--Employ brainstorming techniques
--Encourage flexible thinking
--Ask student to elaborate ideas
--Provide opportunities for open-ended investigation of scientific problems

Objectivity

The teacher will:

--Aid the students in looking for sources of bias in their thinking processes
--Require assertions made by students to be supported by appropriate evidence and logical arguments

Openness to New Ideas

The teacher will:

--Encourage students to look at problems from alternate points of view
--Welcome divergent ideas
--Bring information about recent scientific developments into the classroom and encourage students to do the same

Skepticism: asking "how do we know" as well as "what do we know"

The teacher will:

--Provide evidence supporting scientific statements whenever possible and reasonable: saying X is so and this is how we know
--Require students to support their assertions with appropriate evidence
--Provide opportunities for the students to evaluate the arguments of scientists and pseudoscientists

VIII. Critical/Productive Thinking Skills

The following student outcomes correspond closely to the type of thinking used in the scientific process.

The student will be able to:

--Predict outcomes
--Distinguish between fact and opinion
--Form hypotheses
--Weight evidence
--Analyze information
--Synthesize information

The teacher will:

--Encourage student development of inference and evaluation of argument skills
--Utilize inductive and deductive reasoning
--Encourage logical reasoning
--Encourage syllogistic reasoning

--Encourage student development of inference and evaluation of argument skills
--Utilize indictuve and deductive reasoning
--Ask students to define problems in a question form
--Pose interpretive, open-ended, and evaluative questions for students
--Encourage student development of inference and evaluation of argument skills
--Utilize indictive and deductive reasoning
--Ask analytic questions
--Encourage participation of students in discussion
--Provide opportunities for students to summarize data in various forms
--Withhold own ideas and conclusions

IX. Metacognitive Strategies

These strategies provide a model for helping students think about thinking. Suggested emphases for students are followed by corresponding teacher behaviors.

Planning

The student will be able to:

--Outline scientific procedures to be undertaken
--Order procedures
--Identify relevant materials to be used
--State hypothesis of scientific experiments

The teacher will:

--Provide simulation activities that require student planning.
--Use computer software programs (such as Where in the World is Carmen SanDiego) to illustrate importance of planning and ways to plan.
--Employ cooperative learning strategies to promote the organization of small group/ individual activities.
--Engage in mutual goal-setting behaviors with students.

Monitoring

The student will be able to:

--Assess progress in conducting experiments
--Determine obstacles and create alternatives to them
--Provide solutions to unsuccessful strategies

The teacher will:

--Provide feedback to students at key points in the process of doing science.
--Help student direct or redirect work as necessary.
--Review student plan for carrying out tasks.

Assessing

The student will be able to:

--Evaluate conclusions and draw implications
--Evaluate time and resource management of research
--Evaluate effectiveness of research designs and process used

The teacher will:

--Provide self-evaluation checklist for students (e.g., Did I reach my goal? Is my plan reasonable? Did I use time well?)
--Provide opportunities for students to discuss the process of doing science.

Issues in Using the Scope and Sequence Model for Unit Development

The following section focuses on the ways in which the learner outcomes in this scope and sequence require the curriculum developer to use components of the scope and sequence together, such as concept, content, and science process skills. Any unit developed around this content would be required to satisfy the whole scope and sequence. While the content outcomes demand some obvious parts of the model, other parts would have to be built in by the teacher.

For grades K-2, in the scope and sequence document, we specify the following content outcomes.

A. Grades K-2: Small Ecosystems

For a small ecosystem such as a schoolyard, garden, or self-supporting aquarium or terrarium) the student will be able to:

--Identify the macroscopic organisms present (elements)
--Describe the physical characteristics of the terrain occupied by the ecosystem (elements, boundaries
--Identify instances of symbiotic interactions (parasitism, mutualism, and commensalism) among the different kinds of organisms in the system (interactions)
--Describe the niches of some of the more interesting organisms present (elements, interactions)
--Comprehend the concept of food chains (interactions)
--Identify the components of some of the food chains in the small ecosystem (interactions)
--Describe input into the system (sunlight, rain) and analyze its effects on the small ecosystem (input)
--Describe system output (oxygen, critters, and so on) and analyze its effects on the outside world (output)

These outcomes represent a continuum of concept sophistication from simple to more complex. Individual differences at the K-2 level would dictate the capability of any given learner to become proficient in the concept at this level.

In the typical ecology curriculum for children of this age (based on the basals, which actually contain more detail than do some of the better curricula) whole ecosystems are rarely described in any detail: rather, a few organisms from the ecosystem are described in very general terms, and the child does not get any sense of the biological complexity present. Discussions of the concept of food chains rarely go beyond This is a robin. He eats worms. or Sunlight falls on the grass, which needs sunlight to grow. The cow eats the grass. The cow s meat is used to make Joey s hamburger. That s how Joey ate the sun. While the latter example does include an example of system input, it is relatively shallow. The concept of system input is rarely developed to the next obvious stage, which requires more thoughtful analysis of the interactions of the food chain s elements and of the properties of the ecosystem as a whole. (What would happen if there were no more sunlight? What would happen if the farmer tripled the size of the cattle herd but didn t add more pasture?)

Our content outcomes require a much richer, more detailed treatment of the concept. In addition, they require that the concept be presented in a fundamentally different way. They require that a real ecosystem be actively observed by the students. Active observation necessitates the development of good science process skills, such as notebook-keeping and data analysis; it also suggests the use of technology, such as cameras and computer graphing programs. Deciding what to observe and how to record observations opens up experimental design and metacognition possibilities. Our content outcomes also require the presentation of a number of advanced concepts, including symbiosis and the concept of niche.

How would this work out in practice? Children could examine in detail a real ecosystem because it will present an idea of the true complexity found in even a small area. A small patch of forest, a rotting log, a self-supporting aquarium, a garden: all contain a diverse collection of organisms that the students can observe, catalog, and research.

B. Grades 3-5: Content Outcomes for Local Ecology

For a major local ecosystem (for example, a pond, woodland, stream, farm, or park) the student will be able to:

--Identify as many of the organisms present as is reasonable (elements)
--Map the physical characteristics of the terrain occupied by the ecosystem (boundaries)
--Map the distribution of a representative sample of the different types of organisms in the ecosystem over the terrain occupied by the ecosystem (elements, boundaries)
--For the representative organisms listed above, analyze the niche of each organisms and determine how its structural and behavioral adaptations enhance its survival in that niche (elements, interactions, regulation)
--Analyze the role of humans in the ecosystem (elements, interactions)
--Recognize important system input (rain, sunlight, pollutants, etc.) and evaluate its effect on the system
--Evaluate the importance of the system to the outside world (output)

The content outcomes here require that the concept of niche be developed in great detail with student data. The evolutionary concept of adaptation must also be developed in depth, as the students directly observe the features of organisms (adaptations to their niche) that thave evolved to permit the organism to efficiently compete within the ecosystem.

As before, we require that students observe a real ecosystem in depth, in the field. Thus, scientific process skills are again necessary. Study of adaptive features of organisms lends itself to the development of experimental design skills (What is it about a cactus plant that makes it more fit for desert life than a skink cabbage? Would a cactus do well in a swamp? Would a skink cabbage last for long in the desert? How could you determine this experimentally?) New (compared to the K-2 outcomes) interdisciplinary connections include a large dose of math (required for the design of accurate sampling protocols)as well as the mandated examination of human activities affecting the ecosystem that brings in the nonscience aspects of the problem.

Students could participate in appropriate field trips: they could map out a section of beach and look at the organisms present and their adaptations; they could talk to commercial fishermen and look at the contents of their nets, then correlate the contents with the place fished; they could also talk to the fishermen about the places where different kinds of fish are caught; the impact of man could be assessed by comparing present-day catches with those in the past.

Possible problem-based approaches to this content base might be suggested. They will necessarily depend on the local environment, because field study is a must. For different parts of the country:

1. The local cyclotron is plagued with an infestation of prairie dogs. What should the managers do? (Boulder, Colorado): here students would concentrate on the ecosystem of the field containing the beam dump, the evolutionary adaptations of prairie dogs, their niche, the adaptations of their prey and predators, their distribution, and so on; their niche will suggest geological control mechanisms (introduction of plague into the colony, fostering of baby hawks, use of ferrets and snakes) as well as more drastic measures (make the field into a parking lot).

2. Should wildfires be allowed top burn in Yellowstone? (effect of fire on forest ecosystem; succession; adpatations or organisms to fire).

3. The alligator in the pond next door just ate your neighbor s poodle. Should he be a) shot, b) removed, or c) commended? (Florida)

4. The county board of supervisors wants to build a new high school on a site that is 50% wetland. Is this okay? (Williamsburg)

5. Fire ants are chewing up the telephone lines that the utility company just buried (could be an ecosystem problem, a small animal communities problem, or both) (Texas)

6. How do you control the rat population in Central Park (or, for that matter, in the ivy-covered flowerbeds of Los Angeles?)

Conclusion

Finally, the use of the scope and sequence model as a basis for unit development will depend on the needs of a curriculum context and the creativity of a given teacher. The model, however, provides an important scaffold on which to build an infinite number of specific science units for high ability learners at K-8. This guide has been developed to provide some key ideas for such development.

References

VanTassel-Baska, J. (1992). Effective Curriculum Planning for the Gifted. Denver, CO: Love Publishing Company.

Welch, W. (1986). A research-based approach to science learning. In D. Holdzkom and P. Lutz (ed.), Research Within Reach: Science Education. Washington, DC: National Science Teachers Association.